APPENDIX B
DESIGN CALCULATIONS

I. INTRODUCTION

This appendix presents a description of the general types of calculations that may be required for filter applications. Based on the specific wastewater conditions, additional calculations may be required. Design examples illustrating the use of several of these calculations are presented in Appendix C.

II. PURPOSE

The primary purpose of the filter design calculations is to provide design criteria for sizing equipments for editing guide specifications and developing construction drawings. Based on the preliminary selection of equipment, additional calculations can also be performed to determine parameters such as utility requirements, and supporting mechanical and electrical requirements

III. DESIGN BASIS AND SOURCES

Several types of data sources can be used for the basis of the design calculations. Typical data sources include preengineering reports and treatability studies, standard reference materials, and other sources such as telephone conversations with manufacturers. Any source of data or basis used for the design calculations should be identified and referenced appropriately in the design analysis.

A. Pre-engineering Design and Treatability Studies

Pre-engineering design are typically used as the basis of the design calculations. For HTW applications where package filters will be used, treatability studies may not be practicable or necessary. Each data source used should be clearly identified within the design calculation and properly referenced with the date, title, or other pertinent information that will identify the data source and its validity.

B. Reference Materials

Data and information from reference materials, other than data from pre-engineering reports and treatability studies, can also be used for filter design calculations. Reference materials consist of applicable codes, standards, textbooks, standard tables, and manufacturer's catalogs and examples of manufacturer's literature. Since the ETL focuses on package unit applications, manufacturer's catalogs and literature will provide invaluable assistance. Each reference source used should be properly referenced with the date, title, issue, or other pertinent information to assure complete identification.

C. Telephone Conversation Records

In addition to reference and design data from the design analysis report, telephone conversations to equipment suppliers and manufacturers and regulatory agencies may also be used for the design calculations.

IV. PRESSURE FILTERS

Pressure filters operate with lower filtration rates than gravity filters. Pressure filters can operate on filtration loading rates of 400 L/(min m^2) (10 gpm/ft^2), and terminal head losses of up to 10 m (30 ft) without solids breakthrough. Pressure filters are especially preferred over gravity filters when limited capital resources and space constraints exist for a facility. There is also the advantage of longer filter runs and lessened backwash requirements. Pressure filters, however, require more energy to be run and are more elaborate than gravity filters.

Multiple pressure filter units are used to permit continuous operation during backwashing or maintenance of another unit. The number of units must be sufficient to avoid excessive backwash flow and to properly accommodate flow. The total filter surface area is defined as:

$$\textit{Filter Area } [ft^2,\ m^2) = \frac{\textit{plant flow [gpm, L/min)}}{\textit{filter rate } [gpm/ft^2,\ LI\ (\mathrm{min}\ m^2)]}$$

The total filter area required may then be used to determine the filter bed size. Using standard manufacturer filter bed widths, the filter length may be determined by:

$$\textit{Filter Length } [ft,m] = \frac{\textit{required area } [ft^2,\ m^2)}{\textit{standard width } [ft,\ m]}$$

This total length should be divided where multiple units are desired.

Filtered effluent is used in backwashing pressure filters. As such, the minimum influent is limited to the backwash flow rates required during the cleaning cycle. The minimum influent flow must exceed the backwash flow rate so sufficient effluent will be available for backwashing. Backwash flow rates are determined by the manufacturer.

Solids loading is determined by the equation:

$$\textit{Solids Loading } [lbs/ft^2/day] = 0.01199 \times \textit{Flow Rate } [gpm/ft^2] \times \textit{Suspended Solids } [mg/l]$$

$$\textit{Solids Loading } [kg/(m^2 d)] \quad 1.44 \times \textit{Flow Rate } [L/(\min m^2)] \times \textit{Suspended Solids } [mg/L]$$

Backwash frequency will depend on the types of solids, the solids loading rate, the filter length and the acceptable head loss.

Sizing Filter Piping and Flumes

Each filter within a system should have the capability of operating separately form other filter units. Typical operation of a filter includes piping and valves for influent, effluent, washwater supply, washwater drain, surface wash and filter-to-waste lines. The influent to the filter bed should not agitate the surface of the medium in any way. This may include:

- an initial gullet which disperses the velocity head,
- a throttling control on the influent valve,
- a series of distribution troughs and splash plates.

The effluent washwater supply and filter-to-waste piping is usually manifolded for a common connection with the filter underdrain system. Piping, conduits, gates, and valves are usually designed for the velocities and flows shown in Table 1.

Table B-1
DESIGN VELOCITIES AND FLOW VOLUMES

Flow Description	Velocity, fps	Maximum flow per unit of filter area, gpm/ft^2	Maximum flow per unit of filter area, m/hr*
Influent	1-4	3-8	7.4 - 19.6
Effluent	3-6	3-8	7.4 - 19.6
Washwater supply	5-10	15-25	36.8 - 61.3
Washwater drain	3-8	15-25	36.8 - 61.3
Filter-to-waste	6-12	1-6	2.5 - 14.7

Ref: Design of Municipal Wastewater Treatment Plants, Volume 2: Chapters 13-20; WEF Manual of Practice No. 8, ASCE Manual and Report on Engineering Practice No. 76, Water Environment Federation and American Society of Civil Engineers, 1992.

* m/hr x 16.65 = L/(min · m^2)

Using a given hydraulic design flow of the system, the maximum flow of the system may be determined as:

$$\textit{Maximum Flow } [gpm, L/\text{min}] = \textit{hydraulic design flow } L/(\text{min } m^2) \times \textit{filter area}$$

- Influent Piping and Valve

The area of the influent pipe should be determined using the above maximum flow and a given design velocity (i.e., 0.5 m/sec or 2 fps):

$$\textit{Required Influent Pipe Area } [ft^2, m^2] = \frac{\textit{maximum flow}\,[gpm, L/\text{min}]}{\textit{design influent velocity}\,[fps, m/s]} \; x$$

$$\textit{conversion factor}\,[2.28 \, x \, 10^{-3} \, \frac{cfs}{gpm} \, , \, 1.67 \, x \, 10^{-5} \, \frac{m^3/s}{L/\text{min}}]$$

A required pipe diameter is chosen such that the diameter provides for a velocity within the optimum influent design velocity of 0.3 – 1.2 m/s (1 – 4 fps) (see Table 1) at the above maximum flow.

- Backwash Supply Piping and Valves
Using the given design maximum hydraulic washwater rate for the system and the given filter area, the maximum backwash flow may be determined as:

$$\textit{Backwash Velocity} =$$

$$\textit{design max. washwater rate x filter area x conversion factor}$$

$$[449 \frac{gpm}{cfs}\ ,\ 60{,}000 \frac{L/\min}{m^3/sec}]$$

The required backwash pipe area is determined by the maximum backwash flow and a given design velocity (i.e., 1.2 m/s or 4 fps):

$$\textit{Required Backwash Pipe Area} = \frac{\textit{max. washwater flow}\ [gpm, L/\min]}{\textit{design velocity}\ [fps\ ,\ m/s]}\ x$$

$$\textit{conversion factor}\ [228\,x\,10^{-3} \frac{cfs}{gpm}\ ,\ 1.67\ x\ 10^{-5}\ \frac{m^3/s}{L/\min}]$$

Similar to the influent line, the required backwash pipe diameter is chosen by using a pipe diameter that provides a backwash velocity less than the given design velocity at the above maximum backwash flow, while still being within the optimum washwater supply range of 1.5 - 3.0 m/s (5-10 fps) (Table 1).

- Effluent Piping and Valve
The effluent pipe required area, using the above maximum flow and a given design effluent velocity (i.e., 1.2 m/sec or 4 fps), is determined by:

$$\textit{Required Effluent Pipe Area} = \frac{\textit{maximum flow}}{\textit{design effluent velocity}}\ x$$

$$\textit{conversion factor}\ [2.228\ x\ 10^{-3}\ \frac{cfs}{gpm}\ ,\ 1.67\ x\ 10^{-5}\ \frac{m^3/s}{L/\min}]$$

The required diameter is determined by providing for the optimum effluent velocity range of 0.9 – 1.8 m/s (3–6 fps) (Table 1).

It is important to note that while the effluent maximum flow is the same as the influent maximum flow, the effluent velocity may be different. The effluent velocity usually exceeds the influent velocity.

- Filter-to-waste (FTW) Piping and Valve

The filter-to-waste (FTW) piping should be determined using the maximum system flow and a given design FTW velocity (i.e., 2.7 m/sec or 9 fps):

$$\textit{Required FTW Pipe Area} = \frac{\textit{maximum flow}}{\textit{design FTW velocity}}\ x$$

$$\textit{conversion factor}\ [2.228 x 10^{-3}\ \frac{cfs}{gpm}\ ,\ 1.67\ x 10^{-5}\ \frac{m^3/s}{L/\min}]$$

The required diameter is determined by providing for the optimum FTW velocity range of 1.8 - 3.6 m/s (6-12 fps) (Table B-1).

V. TRAVELLING BRIDGE FILTERS

Generally the filter is sized based on a suggested average and peak hydraulic loading. Typically, manufacturers have suggested hydraulic loading rates of between 4.9 L/(min m^2) (2 gpm/ft^2) and 12.3 L/(min m^2) (5 gpm/ft^2). Increased hydraulic loading will result in increased head loss, possibility of solids penetration and breakthrough, rate of head loss increase, and possibility of surface blinding. If high peak flows in relation to average flow are expected or if peak flows are frequent, peak flow size should govern. The total filter surface area is given as:

$$\textit{Filter Area}\ [ft^2, m^2] = \frac{\textit{plant flow}\ [gpm, L/\text{min}]}{\textit{filter rate}\ [gpm/ft^2, L/(\text{min}\cdot m^2)]}$$

Once the total filtration area required has been defined, the exact size of the filter bed can be determined. Manufacture-r*s will have standard bed widths. The filter length will be determined by:

$$\textit{Filter Length}\ [ft, m] = \frac{\textit{required area}\ [ft^2, m^2]}{\textit{standard width}\ [ft, m]}$$

Where multiple units are desired, the total length should be divided between the desired number of filter units.

Since the filtered effluent is used for backwash, minimum influent is limited by the backwash flow rates required during the cleaning cycle. The minimum influent flow must exceed the backwash flow rate so sufficient effluent will be available for backwashing. Backwash flow rates are determined by the manufacturer based on bed size.

Solids loading should also be considered in sizing the filter. This can be measured in solids loading which is expressed in lbs/ft^2/day. Solids loading is determined as follows:

$$\textit{Solids Loading}\ [lbs/ft^2/day] =$$

$$0.01199 \times \textit{Flow Rate}\ [gpm/ft^2] \times \textit{Suspended Solids}\ [mg/L]$$

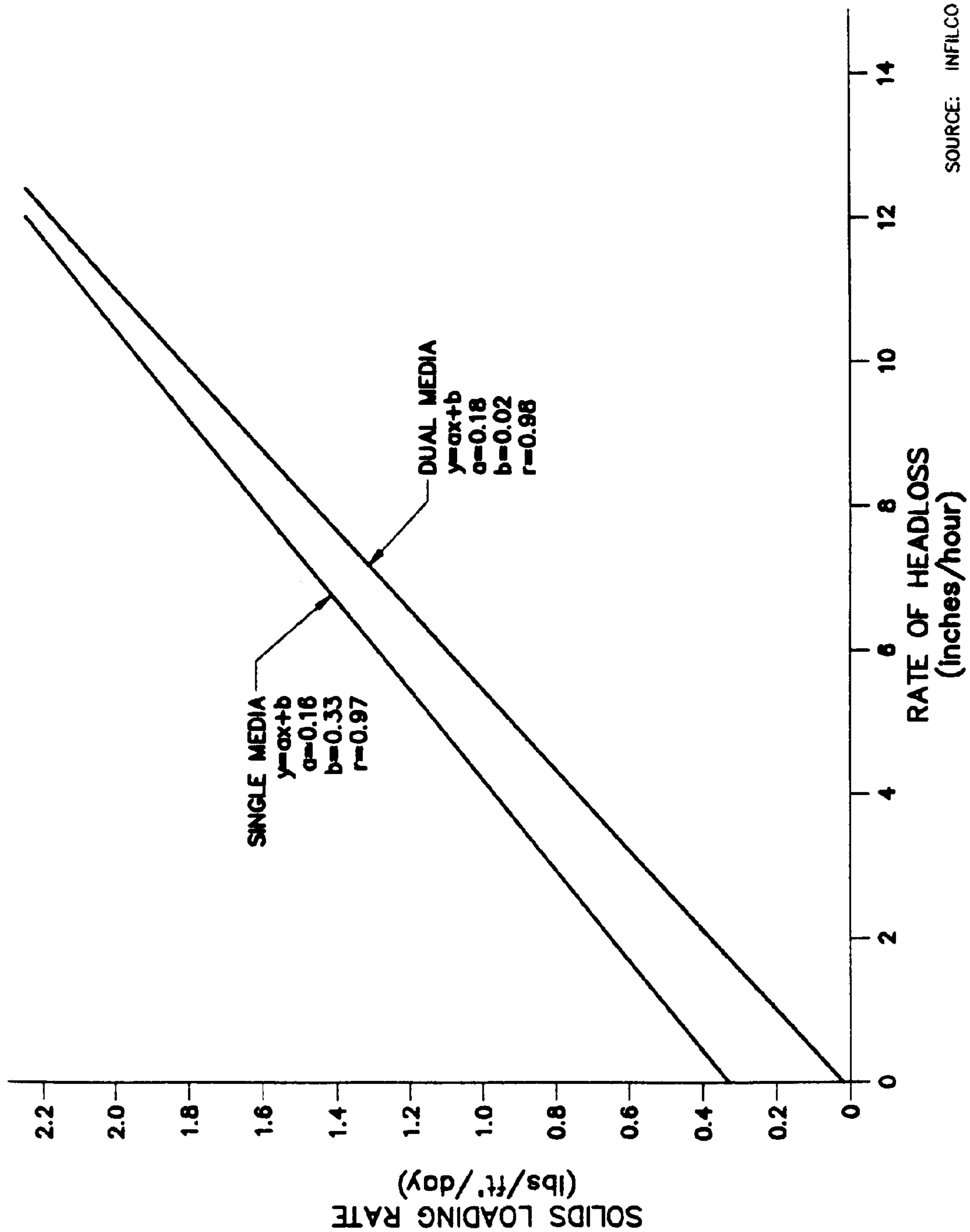

FIGURE B-1. SOLIDS LOADING RATE VERSUS RATE OF HEAD LOSS.

SOURCE: INFILCO DEGREMONT, INC.

APPLICATION GUIDELINE

WATER TREATMENT APPLICATION	LOADING RATE (GPM/SQ.FT.)	MAXIMUM INLET SOLIDS (MG/L)	EXPECTED EFFLUENT SOLIDS (MG/L)	APPLICABLE PARTICLE SIZE
Surface Water	2 - 6	10 - 100 NTU	0.1 - 0.5 NTU	9 - 12 microns
Tertiary Filtration	3 - 5	150	< 5 - 10	9 - 12 microns
Phosphorus Removal	3 - 5	10 (as P)	< 0.3	9 - 12 microns
Pulp & Paper Effluent	3 - 5	100	5 - 10	9 - 12 microns
Metal Finishing	3 - 6	200	2 - 5	9 - 12 microns
Mill Scale	8 - 12	500	5 - 10	9 - 12 microns
Oily Wastewater	2 - 6	200 (free oil)	5 - 10 (free oil)	9 - 12 microns
Algae Removal	2 - 4	100	10 - 20	9 - 12 microns

MODEL NUMBER	AREA (SQ. FT.)	INSIDE DIAMETER (FT)	HEIGHT			FLOWRATE		AIR	SAND
			INLET	OUTLET	REJECT	EFFLUENT	REJECT	REQUIREMENT	
1	7.0	3.0	13'7"	11'0"	10'9"	14-42 gpm	2-15%	0.6-1.3 scfm	1.6 tons
2	12.5	4.0	13'4"	12'4"	11'11"	25-75 gpm	2-15%	0.6-1.3 scfm	3.3 tons
3	19.0	5.0	14'1"	13'1"	12'8"	38-114 gpm	2-15%	1.0-2.0 scfm	5.0 tons
4	38.0	7.0	15'6"	14'4"	13'11"	76-228 gpm	2-15%	2.0-3.0 scfm	9.5 tons
5	64.0	9.0	20'6"	18'11"	18'11"	128-384 gpm	2-15%	3.0-4.0 scfm	20 tons

$$Solids\ Loading\ [kg/m^2/day] =$$

$$1.44\ x\ Flow\ Rate\ L/(min\ m^2)\ x\ Suspended\ Solids\ [\text{mg/L}]$$

Figure 1 is a sample curve of head loss increase versus influent solids loading rate for both dual and single media filters. Typically designs with loading rates greater than kg/(m^2 d) (1.0 lbs/ft^2/day) should be approached with caution.

Frequency of backwash will be dependent on the type of solids, solids loading rate, filter length and acceptable head loss. Frequency of backwash is calculated using Figure 1. The increased head loss may be determined from the solids loading rate. The time required to reach terminal head may be determined by dividing the operating head by the rate of increased head loss. The time required for the carriage to transverse the filter during the backwash cycle is available from the manufacturer. The total time required from completion of one backwash cycle to the completion of the next backwash cycle is the sum of the traversing time and the time required to reach terminal head. Dividing 24 hours by the total time will provide the number of backwash cycles per day.

The percent of backwash water required per day is determined by:

$$Backwash\ Water\ Required\ [gal,\ L] =$$

$$Backwash\ Flowrate\ [gpm, L/\text{min}]\ x\ Traversing\,Time\ [\text{min}]\ x\ \frac{Backwashes}{day}$$

The total throughput is then calculated by:

$$Throughput\,[gal, L] = Filter\,Area\,[ft^2, m^2]\ x\ Flow\,Rate\,[fps, L/\text{min}]\ x$$
$$conversion\ factor\,[7.48\,\frac{gal}{ft^3}\,,\,1000\,\frac{L}{m^3}]$$

Percent backwash is the backwash water required divided by the total throughput. Backwash water requirements below 2—4% are common (Infilco Degremont, Inc.). The requirements are incorporated into design as hydraulic loading.

VI. CONTINUOUS BACKWASH FILTERS

Since all continuous backwash filters are proprietary systems, relatively little flexibility is available in selecting the unit once a single manufacturer has been chosen. Similar to the approach for sizing a travelling bridge filter, the manufacturer will determine filter size based on flow rate and hydraulic loading. Hydraulic loading rates may vary between 80-500 L/(min m^2) (2-12 gpm/ft^2), with a typical rate of 200 L/(min m^2) (5 gpm/ft^2). The attached applications guideline table gives acceptable loading rates for particular water treatment applications. The manufacturer can provide further guidance on acceptable hydraulic loading rates for an influent stream with a given total suspended solids concentration and solids size and density. Using the plant flow and the hydraulic loading, the filter area is determined as:

$$Filter\ Area\ [ft^2, m^2] = \frac{plant\ flow\ [gpm, L/\text{min}]}{hydraulic\ loading\ [gpm/ft^2, L/(\text{min}\cdot m^2)]}$$

Once the required filter area is determined, the filter may be selected. The attached sample application table show typical sizes available and the requirements for tank size, reject percentage, air flow and media for the appropriate filter.

VII. CARTRIDGE AND BAG FILTERS

Summarized below is a general approach to designing cartridge and bag filters. The design approach assumes that cartridge or bag filtration has already been selected as the filtration method of choice. Many of the steps involved in selecting cartridge or bag filters and the hardware for housing the filters is the same. Where there are differences it will be noted in the text. All supplier bulletins referenced in the text are at the end of this section.

The first step in selecting a cartridge or bag filter is to identify the contaminants present in the waste stream to be filtered and identify filter materials of construction which are compatible. This is done by comparing the waste stream components to vendor compatibility charts. One page of a chemical compatibility chart with polypropylene cartridge filters, published by a vendor can be seen in the design example in Appendix C. The filter components that need to be checked for compatibility is the filter media, support core and/or outer cage and O—rings to be used. Several materials of construction may be suitable. Alternatively, some vendors suggest conducting your own chemical resistance test by following the procedure outline below.

- Immerse a cartridge or bag filter of the desired micron rating in the fluid to be treated and at the desired operating temperature for at least 48 hours.

- Examine the cartridge for any change in color, structural integrity, swelling, softening, deformation or any other physical changes.

- Observe the solution to see if any chemical reaction has taken place. Check for changes in color, clarity, viscosity, etc.

- If there has been no perceptible change in the cartridge or solution, then the filter may be considered for use.

Having selected the material of construction check which materials can operate in the temperature range of the waste stream to be treated. Some materials of construction can only operate at temperatures up to 70°C (160°F) while other materials can operated at temperatures up to 300°C (600°F).

Based on influent suspended solids and particle size data select the micron rating for the filter to meet desired effluent suspended solids and particle size criteria. Note that the smaller the micron rating the lower the solids holding capacity of the filter. For example, a wound cotton cartridge filtering a liquid with 1 ppm solids feed rate would have the following holding capacities at various micron ratings.

Micron Rating	Solid Holding Capacity

micrometers	grams per unit filter
1	15
5	35
10	60
20	100

The above data was generated at a 10 L/min (2.5 gallon per minute) flowrate on a 250 mm (10 inch) filter and failed at a maximum pressure differential of 240,000 Pa (35 psi). See “Chemical Engineering”, January 18, 1988 for additional information on selecting cartridge filters. Actual solids holding capacity should be checked under process conditions since many filter manufacturers rate the solids holding capacity under controlled laboratory conditions and actual solids holding capacity can vary significantly.

The fluid viscosity at the operating temperature should be determined. If the system will be operating under varying conditions then the temperature which gives the highest viscosity in centipoise must be known.

At this stage of design the following filter selection criteria have been identified:

- Materials of construction for the filter based on waste stream compatibility and maximum operating temperature.
- Micrometer rating of the filter based on influent conditions and desired effluent quality. Typically this information is provided in vendor literature.
- Solids holding capacity of the filter from vendor literature or bench/pilot testing of the process stream.
- Maximum viscosity of the fluid to be treated.

The designer can now use vendor application literature to determine the number of filters required for design flowrate. A copy of the Vendor A Polypro pleated type cartridge filter bulletin is provided in the design example. Based on the system flow the designer must next select a flow rate in gpm/unit filter. The designer needs to confirm from the filter supplier or their specification bulletin what the maximum flowrate per unit filter or flowrate per square foot of filter area is. In the case of this example the supplier would need to be contacted. To determine the number of filters required the following equation can be used:

$$\frac{\textit{System Flowrate}}{\textit{Flowrate Per Unit Filter}}$$

The number of filters used can be altered by using filters with lengths greater than 10 inches. There are standard cartridge filter lengths up to 1 m (40 inches).

To determine the pressure drop per filter use the Water Flow Rate/Differential Pressure curves as shown in the Vendor A bulletin in the design example. Each supplier must be consulted to determine how they account for fluid viscosities greater than 1 centipoise (one centipoise being clean water at standard temperature and pressure). An example of how Osmonics accounts for changes in viscosity for their Hytrex filter line is provided as an attachment. For this example Vendor A uses a maximum flowrate of 20 L/min/250 mm (5 gpm/10 inch) length of cartridge to account for fluids of any viscosity.

Having identified the number of cartridges the system housing needs to be selected. As with the filter the materials of construction should be chosen based on compatibility with the waste stream being treated including chemical compatibility, temperature and operating pressure. The internal components of the housing need to be selected so that they are compatible cartridge ring configurations. An EXCEL bulletin on multiple cartridge housings is provided in the design example. The following housing components need to be specified by the designer.

- Ring Cartridge configuration
- Materials of construction
- Number of and length of filter elements per housing
- Inlet/Outlet styles, side in/side out, side in/bottom out

Number length of filter elements per housing is not only determined by the number and length of filters determined by design but it is also based on standard housing configurations from the supplier. For example, the system may require the use of 20–500 mm (20-20 inch) filters but the suppliers standard housing may be designed for 24-500 mm (24–20 inch) filters. In this case the four extra filters will improve performance. If the suppliers standard housings accommodate some number of filters less than the design quantity, then the designer should consider the impact on performance due to increased hydraulic and solids loadings or parallel operation of smaller housings.

Inlet and outlet style selection is based on how the filter housing is to be piped into the rest of the system and not necessarily on system hydraulics. Items such as inlet and outlet connections are often preselected by the supplier based on the maximum flow ratings per filter system.

To determine approximate run time between filter changes use the following equation

$$\textit{Run Time [days]} = \frac{\textit{Solids Loading, 250 mm filter x Number of 250 mm Filters}}{\textit{Feed Suspended Solids Concentratrion x 1440 min/day}}$$

VIII. SUPPORT FACILITY REQUIREMENTS

Based on the initial selection of equipment, utility requirements for ventilation, power, water, air, telephone, and other utilities can be determined. Although some of these calculations may be determined as requirements for the entire treatment facility, incremental calculations may be required that apply specifically to equipment or facilities required for the filter operation. Generally, for the package systems addressed, the manufacturer will supply required information.

In addition to utility requirements, additional design and calculations related to architectural and structural components will be required. These types of calculations are application specific, and therefore no specific calculations are provided.